TRENDS IN CYPRINID POLYCULTURE

by

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ABSTRACT. - Polyculture is the association of fish species, mostly cyprinids, feeding at different levels of the aquatic pond ecosystem. It is an efficient food production system, which typically produces five tonnes of fish/ha/year without distribution of formulated artificial feeds but with intense organic fertilisation as well as grass and agricultural by-products. The exact figures of polyculture production in the world are not known precisely. A part of the production of cyprinids is due to monoculture of the grass carp and the common carp, both of which accepting artificial feeds. An estimate of the trends is given by the production of cyprinids specifically produced by the polyculture of Chinese carps in China (especially the silver carp and the bighead) and the major Indian carps on the Indian subcontinent. The total production of all carp species has increased over the last decade but the rate of increase has slowed down after 1997 in China for the silver carp and the bighead. In general, the commercial value of cyprinids is low, about $1 per kg. To compensate for this low price the fish farmers are looking for intensification of production and for species of higher commercial value. In polyculture systems the availability of natural food is the main limiting factor. It is not possible to increase the productivity above 10 t/fish/ha/year, as adding more external poor quality feeds results in degradation of water quality and dysfunction of the ecosystem. A new form of polyculture in China is to intensify the production by feeding the fish with good quality manufactured feeds to avoid degradation of the water quality and to use silver carp and bighead to control the development of planktonic blooms. There is then a tendency towards replacement of polyculture by intensive monoculture of cyprinids and by new and more valuable species (tilapia, sturgeon, American and African catfish). If polyculture systems were converted to monoculture or less efficient polyculture (using new species) this would result in a decrease of the world production of fish in culture and of the global efficiency of aquaculture. In general, research programmes carried out to develop polyculture are more focused on the fish (genetics, artificial feeding, disease) in China and on pond productivity (artificial substrates, use of periphyton) in India. These technical improvements should increase the profitability of polyculture and assure its future as an efficient food production system.

RÉSUMÉ. - Tendances actuelles de la polyculture des cyprinidés.

La polyculture est l'association, dans un même étang, de plusieurs espèces, en général des cyprinidés, s'alimentant aux différents niveaux trophiques de l'écosystème aquatique. C'est un système de production très efficace qui produit communément cinq tonnes de poissons par hectare et par an, sans apport d'aliments artificiels sophistiqués, mais en conditions d'intense fertilisation organique et apports de sous-produits agricoles. Les productions exactes de la polyculture dans le monde ne sont pas connues. Une partie de la production de cyprinidés est due à une monoculture intensive de carpe commune et de carpe herbivore. Une estimation des tendances de l'évolution de la polyculture est donnée par les courbes de production d'espèces spécifiquement issues de la polyculture comme la carpe argentée, la carpe marbrée et les carpes indiennes majeures. Toutes ces espèces ont vu leur production augmenter à l'exception des carpes argentée et marbrée dont la production a tendance, en Chine, à se stabiliser après 1997. En général, la valeur marchande des cyprinidés est faible (environ 1 $ par kg). Pour compenser ces bas prix, les pisciculteurs intensifient la production d'espèces classiques et se reportent sur des espèces plus chères. Dans les systèmes de polyculture, les disponibilités en aliments naturels représentent le facteur limitant majeur, et la production ne dépasse pas 10 tonnes de poissons par hectare ; en effet l'addition massive d'aliments extérieurs se traduit par une dégradation de la qualité de l'eau et un disfonctionnement de l'écosystème. Une nouvelle forme de polyculture en Chine est d'intensifier la production de carpe commune, de carpe herbivore ou d'espèces de meilleure valeur commerciale (tilapia, esturgeon, poisson-chat américain) par apport d'aliments de bonne qualité qui ne dégradent pas la qualité de l'eau, et d'introduire des carpes argentée et marbrée pour contrôler le développement du plancton. La polyculture tend alors à être remplacée par un élevage intensif de cyprinidés associés à des espèces de plus grande valeur, ou introduites pour protéger l'espèce principale, ce qui peut être qualifié de co-culture. Si les étangs de polyculture se convertissent en monoculture ou en systèmes de polyculture moins performants, utilisant de nouvelles espèces, cela se traduirait par une diminution de la production mondiale de poissons et une réduction de l'efficacité globale de l'aquaculture déjà mise en question. Globalement, les activités de recherches destinées à développer la polyculture portent sur le poisson lui-même, en Chine, et sur la productivité des étangs en Inde. L'optimisation des technologies de production devrait permettre à la polyculture en étang d'eau douce d'améliorer sa productivité et de rester économiquement compétitive face à la monoculture.

Key words. - Cyprinidae - Carps - China - India - Polyculture.

Polyculture is the cultivation in a single pond of mixed stocks of fish with complementary or minimal competing feeding habits and different ecological requirements. Such systems use different levels of the aquatic food web in the pond (algae, aquatic plants, zooplankton, benthos) and allow maximal fish production for the available food. The number

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of species present in conventional polyculture systems is limited; Dabbadie and Lazard (2001) identified and described the characteristics of seven cyprinids and the Nile tilapia *Oreochromis niloticus* that is commonly used in polyculture. The number of species introduced in the system depends on the variety and quantity of food available. The main fish polyculture systems are found in China and India. They are mostly based on cyprinids but other groups were introduced recently. Polyculture ponds integrated to animal husbandry and agriculture is well developed in Asia (Sinha, 1986). The ponds are highly fertilised with various by-products from agriculture such as manure or wastes (Fig. 1). Also grass and cereals produced on the farm are distributed into the pond as complementary feeds (Edwards, 1993). Polyculture is an efficient food production system, which produces commonly 5 tonnes of fish/ha/year without distribution of artificial feeds. It may reach up to 10 tonnes of fish/ha/year with various agriculture by-products as feeds; this productivity is much higher than in any other system of animal production based only on the consumption of primary production (grass).

The total production of cyprinids in the world was 16 million tonnes in 2000, but the exact figures for polyculture production are not known as some cyprinids are produced in monoculture such as the grass carp *Ctenopharyngodon idella* and the common carp *Cyprinus carpio* in several countries (for instance in Japan for the common carp). In China and India-Bangladesh, a large proportion of the cyprinids produced (14 million tonnes in 2000) is from polyculture. The cyprinids specifically produced in polyculture are the Chinese carps (especially the silver carp *Hypophthalmichthys molitrix* and the bighead *Aristichthys nobilis*, which are not suitable for culture with manufactured feeds) and the major Indian carps. Over the last decade the production of these cyprinids showed a regular increase in China and India (Figs 2, 3). However in China the rate of increase was lower after 1997 and production has nearly reached a plateau, suggesting that polyculture does not increase much. This is true for the silver carp and the bighead, which are the typical species exclusively produced in polyculture. The trends and challenges of this efficient system of production, which yields more than one half of the total volume of fish cultured in the world, are reviewed in this paper.

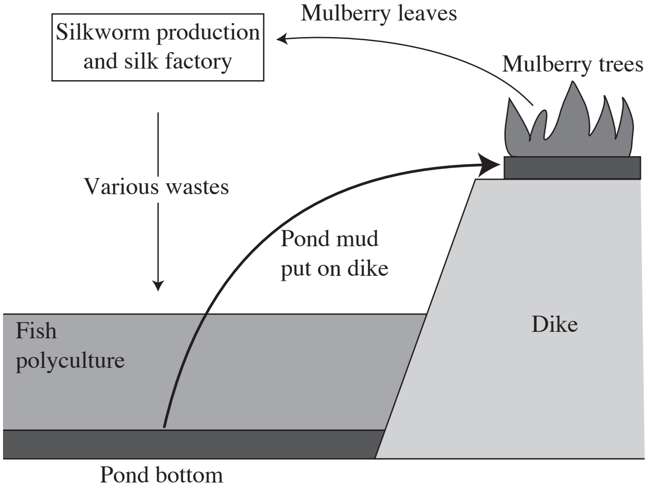

Figure 1. - Representation of a mulberry-dike fish pond system in the Zhujinang River Delta (after Ruddle and Zhong, 1988). Various wastes include silkworm faeces, silkworm chrysalids, cocoon, silk factory wastes.

The Chinese polyculture

In China more than 10 endemic species can be associated in polyculture systems. The most prominent are the silver

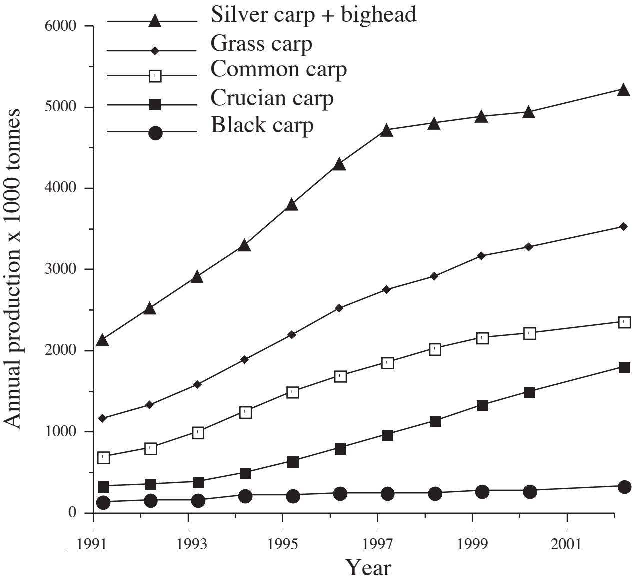

Figure 2. - Changes in the annual production of some carp species used in polyculture in China (FAO, 2000, statistics for 1991 to 1998 and Li (pers. comm.) for 2000).

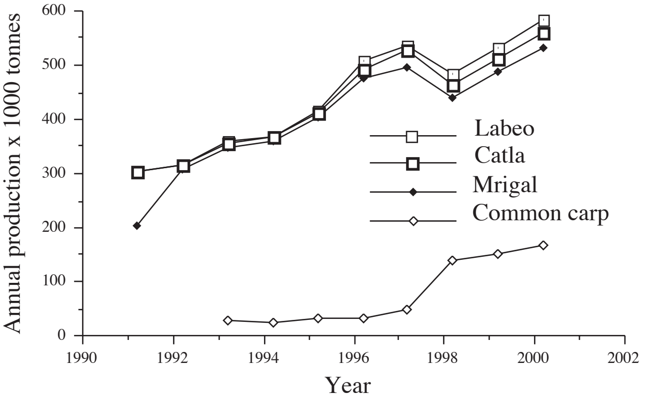

Figure 3. - Changes in the annual production of Indian major carps and common carp in polyculture in India and Bangladesh (FAO statistics for 1991 to 1998).

Table I. - Example of polyculture with grass carp as main species (after Li and Mathias, 1994).

	Stocking			Survival (%)	Harvest	
	Size (g)	No	Weight (kg/ha)		Size (kg)	Yield (kg/ha)
Ctenopharyngodon idella	400-500	3,000	1,200.00	90	1.70	3,390
Ctenopharyngodon idella	50-100	4,500	225.00	80	0.50	1,575
Megalobrama amblycephala	33-50	4,500	150.00	90	0.20	660
Hypophthalmichthys molitrix	150-250	600	120.00	95	0.60	225
Hypophthalmichthys molitrix	50-100	2,400	165.00	90	0.60	1,125
Hypophthalmichthys molitrix	3 cm	3,700	1.88	80	0.10	300
Aristichthys nobilis	150-250	150	30.00	95	0.60	60
Aristichthys nobilis	50-100	600	45.00	90	0.60	285
Aristichthys nobilis	3 cm	1,050	0.53	80	0.10	90
Cyprinus carpio	25	1,500	37.50	90	0.50	645
Carassius carassius	10	2,250	22.50	90	0.15	300
Oreochromis niloticus	2.5	3,000	7.50	80	0.15	360
Total			2,005.00			9,015

Table II. - Production of the main cyprinid species in the world in 2000 (FAO, 2000).

	Number of countries	Production x 1000 t	Main producers	%
Hypophthalmichthys molitrix	40	3,473	China	93
Ctenopharyngodon idella	43	3,447	China	92
Cyprinus carpio	90	2,718	China	78
Aristichthys nobilis	20	1,637	China	99
Carassius carassius	12	1,379	China	99
Labeo rohita	5	795	India	71
Catla catla	4	653	India	99
Parabrama pekinensis	1	511	China	100
Cirrhinus mulitorella	3	180	China	100
Mylopharyngodon piceus	3	171	China	99

carp and the bighead feeding on microalgae and zooplankton, the grass carp on macrophytes, the common carp on zoobenthos and macrozooplankton. Some other species are also introduced, taking advantage of other niches such as the black carp *Mylopharyngodon piceus* Richardson, that eats molluscs and the crucian carp *Carassius carassius* L., that eats detritus. A pond typology has been established that defines the most appropriate associations of fish. Those may be complex and include up to 7 species (Tab. I). Numerous species are hard to handle because of the difficulty to obtain juveniles at the right time for each species, and problems at harvesting and sorting (Billard, 1985).

Polyculture is also practised on more complex systems such as the dike-pond integration of the Zhujiang Delta (Guandong Province), which integrates efficiently agriculture crops and fish farming. Several systems were identified based on association of fish with culture of mulberry (Fig. 1), sugar cane/rice field, fruits,... Management of plants for fish crop integration has been described in China by Yang *et al*. (1992). They identified 12 different plants produced on pond dikes and drained pond bottoms. Plants were made available during the entire growing season. The yield was in the range of 17 to 50 kg of plant (wet weight) to produce 1 kg of live fish. To gain 1 kg, black carp needs 50 kg of molluscs.

Indian polyculture

Indigenous polyculture systems have existed for centuries in South-East Asia, India, Indo-China, Cambodia. The major Indian carps, catla *Catla catla* Hamilton, rohu *Labeo rohita* Hamilton, mrigal *Cirrhina mrigala* Hamilton, and calbasu *Labeo calbasu* Hamilton, have been cultured for centuries in the north-eastern states of India probably in polyculture systems but it was, as in China, simply the growing on of young wild fish caught in nature. The fact that there was no control of reproduction and consequently no selective breeding (not even mass selection) explains why no full domestication has occurred and why fish culture was based until recently on wild juveniles, a practice that has continued for a millennium. In general, 3 species are associated: catla feeding on plankton (64% crustacean, 30% micro-algae), rohu taking periphyton, rotten vegetation and mrigal consuming various detritus (Tripathi, 1990). A so-called composite culture is also practised. It is rather complex and includes the three Indian major carps, the common carp, the “Chinese carps” and three other species *Pangasius pangasius* Hamilton, *Ompok bimaculatus* Bloch, *Notopterus chilata* Hamilton, feeding respectively on molluscs, insects and weedfish (Jhingram, 1986). As in China these systems are deeply integrated with agriculture and represent an efficient way of recycling wastes.

Some other polyculture systems

In Europe, fish culture started in monastic ponds in the Middle Ages with some cyprinids, especially the common carp introduced earlier by the Romans. Fish had a religious significance (to be consumed once a week at least by the monks) but also a social importance (it was eaten on special occasions, for example Christmas and still is, for example in the Czech Republic). The most common species produced in pond culture are the common carp in association with tench *Tinca tinca* L., roach *Rutilus rutilus* L., rudd *Scardinius erythrophthalmus* L., gudgeon *Gobio gobio* L., and often more valuable predators like pike *Esox lucius* L., or perch *Perca fluviatilis* L. There is some kind of integration to agriculture (Muir, 1986; Olah, 1986) but the productivity is much less than in the Chinese and in the Indian systems. Some fertilisers and cereals are distributed in the pond and the production may reach 1 t/ha/year. Polyculture production in Western Europe is not significant and now ponds have some patrimonial value offering original landscapes in the countryside and are used in many cases for sport fishing and recreation (Lutz, 2001).

Why was Chinese polyculture successful only in Asia?

Cyprinid species are numerous and widely distributed. Their success in culture is due to their physiological characteristics, especially the capacity to live in a large range of temperature and water quality conditions, and to their good growth with acceptable food conversion coefficients. The number of phytophagous fish species in the world is limited and phytophagous carps are mostly found in Asia so that there was little chance to have polyculture systems established historically in the other continents.

In the recent past, the introduction of the Chinese polyculture system to other countries was often attempted with some success in some Asian countries like Nepal, Laos, Bhutan (Csavas, 1993). Chinese carps were successfully introduced in the former Soviet Union in 1959 and from there to the Middle East and Europe. As a result, the Chinese polyculture system was temporarily established in the Soviet Union and in several central European countries (Romania, Hungary, and Czechoslovakia). Presently no major production of Chinese carps is reported in those countries (with the exception of Iran, which produces 5,500 t per year). Altogether phytophagous fish were introduced into more than 40 countries in the 1970s and 1980s (Welcomme, 1988) where they are still present. Data in table II shows that the main Chinese carps from polyculture are still mostly produced (97-99%) in China. Similarly, most of the Indian major carps are produced in India. Finally, outside China, there has been no major development of the Chinese polyculture systems, in term of quantity of fish produced. The polyculture of the Indian major carps also remained restricted to the Indian sub-continent.

Problems raised with polyculture systems

Fish ponds and public health

The problem of safety of aquatic products and public health considerations concerning fish grown in manured ponds or in waste-water-fed ponds has been raised in the past. When fish are grown in ponds containing more than 10^4 to 10^5 faecal coliforms /ml, invasion of fish muscle by bacteria is likely to occur, especially if the fish are stressed. However, most bacteria are part of the food chain and contribute to the fish growth; in well managed ponds the algae-bacteria interaction is detrimental to pathogenic micro-organisms, fish are not stressed, they show high growth in bacteria concentration of 10^6 and few bacteria were found in the muscles. As an example, Turner *et al*. (1986) using chlorinated secondary domestic sewage effluent as fertiliser for marine aquaculture founded coliforms (*E. coli*) in the effluent but not in the flesh of tilapias, mullets and prawns. No enteric virus was detected. Bioaccumulation of heavy metals was found in algae and daphnia and only copper and zinc in the flesh at concentrations near the legally permissible levels. Chlorinated hydrocarbon pesticides were measured in cultured fish and prawns at levels slightly below the permitted maximum. In a review, Phillips (1993) concluded that several trace metals, dioxins, dibenzofurans and PCBs were below the permitted limits in aquatic animals in general, but only few (Hg, Cd) were present in aquaculture products and not all constitute toxicological threats. Scholtissek and Naylor (1988) have suggested that human influenza pandemics may result from genetic reassortment between human and avian influenza virus in pig in integrated aquaculture systems, but this assumption has not been confirmed.

Ecological and technical problems

Ye (2003) identified several major problems in the Chinese polyculture: slow growth of fish, poor resistance to diseases and earlier maturation, which were related to genetic degeneration. These problems are caused by deterioration of the pond ecosystem; the water quality decrease due to large amount of organic matter introduced, the industrial pollution and poor feeding practice. Fish diseases occurred frequently; *Aeromonas hydrophila* was recognised as associated with diseases outbreaks. The supplementary feeds are of poor quality and the fish farmers tend to move to high quality manufactured feeds.

Although polyculture is very efficient in recycling wastes and preventing the release of dead organic matter in the environment, less than 2% of the solar energy PARE (Photosynthetically Active Radiation) is converted into fish (Ruddle and Zhong, 1988). Similar figures were given by Li (1987) in a typical Chinese integrated fish farm; 1.15% of the solar energy was converted into fish biomass. This is partly due to the benthic fish species which increase the turbidity of water and decrease the penetration of the solar energy. Also the manure used is often of a poor quality and is dropped straight into the ponds without fermentation. However properly managed manuring with pig dung has a beneficial effect on fish production (Dhawan and Kaur, 2002). Pond culture requires large volumes of water due to evaporation (> 1 m height per year) which is a problem as the world is facing a shortage of freshwater. There were also some rejections by the Chinese consumers of fish exposed to human excreta but this practice was discontinued. For instance, in the early 1980s in a polyculture system at the Nanhui fish farm in China, Li (1987) reported in a two-year period a 33% decrease in the use of human manure and a rise of 73% in the use of pelleted feeds while the net productivity increased by 17%.

Economical problems

In the context of the transition from a planned economy to a market economy, it seems there is no regulation that apply to fish farming. After the Cultural Revolution (1966-1978) and the new emerging economy, the individual family started to change the allocation of capital and labour to the pond system. In general the commercial value of cyprinids is low, about $1 per kg (world cyprinid culture yields 15.7 million tonnes for a total value of $15.3 billion). To compensate for this low price the fish farmers are looking for intensification of production. They are also looking for species of higher commercial value. The polyculture system is labour intensive (mud excavation, handling and harvesting several species), which increases the production costs. Green manure tends to be replaced by pelleted feeds and mud excavation to repair the dikes or to fertilise the plants on the dikes is being discontinued (Li, 1987). In addition the collapse of the silk industry reduced the mulberry demand and no substitute was found. Amy (1999) has observed a decline of polyculture and the development of a more sophisticated and intensive monoculture in the pond dike fish culture system in the Zhujiang Delta in the 1984-1994 period, *i.e.*, starting six years after Deng's reform. The productivity and the profit are higher in monoculture due to a more intensive use of the ponds and other structures and the production costs decrease. The average Chinese productivity per hectare has increased regularly during the past years (Fig. 4). This is due to intensification with use of manure, cereals, and intensive aeration. Further intensification cannot be achieved in polyculture systems, which start to be replaced by intensive monoculture with more external inputs (oxygen, pelleted feeds) reaching productivity well above 10 t/ha/year. Currently China produces 5 million tonnes of pelleted feeds for aquatic animals which require the import of 650,000 tonnes fish meal (D'Abramo *et al.*, 2002), this partly serves to produce carnivorous marine fish (400,000 tonnes produced in 2000; Hong and Zhang, 2001) and shrimps but a significant part is distributed to freshwater ponds.

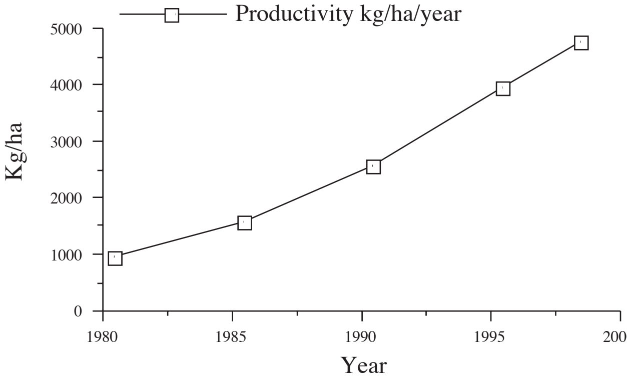

Figure 4. - Changes in fish productivity (Chinese average values) in freshwater ponds during the past 20 years (after Li, 2001).

Changes in the polyculture technologies in China

Polyculture technology is now changing in China; along with the abandonment of the use of human manure (S. Li, pers. comm., 2003), good quality feeds are given to the fish in ponds so that the deterioration of the water quality is reduced as the silver carp and bighead are still present to control plankton blooms (S. Li, pers. comm., 2003). Still polyculture systems are sometimes technically inefficient with improper choice of species combination and there is room for the improvement in the species association from technical and economical points of views (Sharma *et al.*, 1999). New forms of polyculture mostly based on macroalgae are merging especially in developed countries to remove the nutrients, which are released from the fish farms into the environment or to protect the main species (co-culture) (Neori *et al.*, 2004; Billard, 2004).

During the last 20 years the polyculture of cyprinids has contributed significantly to the increase in total fish production from aquaculture. There is now, particularly in China, a tendency to produce in ponds traditionally devoted to polyculture more valuable species (various sturgeons, tilapia, eel *Anguilla japonica* L., channel catfish *Ictalurus punctatus* Rafinesque, shrimps, soft shelled turtle *Tryonyx sinensis* Wiegm) in monoculture giving higher economic return, at least in the short term. Association of tilapia with shrimp has been proposed (Wang *et al.*, 1998). Guo (2000) mentioned that the culture of high valued species was growing at a much faster rate than traditional species. Polyculture remains efficient from an ecological point of view. If it is replaced by monoculture or less efficient polyculture (using new species) (Billard, 2004), there would be a decrease of the world production and a reduction of the global efficiency of aquaculture which has already been questioned (Naylor *et al.*, 2000). To keep the production at the same level, large amounts of pelleted feeds would be needed requiring other food sources such as fish meal, fish oil, cereals and plant protein. As more organic matter is released into rivers and lakes (and less is consumed in ponds), some risks of eutrophication of natural water bodies and pollution would occur. In addition, the new species of higher value will be exported and will not be consumed locally; there would be less food for the local people. Guo (2000) stated that China has a market for luxury fish. However, the shift from polyculture to monoculture is still limited and it is not reflected in the statistics of aquaculture production (Figs 1, 2).

Research support to polyculture

In China, some information on research activity or future projects in the field of polyculture were given by Li (2001) and Ye (2003). Work is underway in carp genetics (selective breeding, hybridization, transfer of growth hormone gene,…), vaccination for preventing infectious diseases, nutrient requirements of the Chinese carps, manufacture of artificial feeds of high quality, water treatment, improvement of culture techniques and carp processing. Sharma *et al.* (1999) have concluded that modern fish farming techniques are crucial to improve the productive performance of pond fish culture in China.

In India, in addition to current studies on larval nutrition, original research has started on the use of artificial substrate in ponds to improve the production and the use of periphyton (biofilm), which is a mixture of autotrophic and heterotrophic organisms. As the fish yield is no more than 1% of the energy fixed by the phytoplankton, the idea is to make a better use of the primary production. Physical supports are introduced in polyculture ponds such as tree branches and bamboo sticks on which periphyton develops and is consumed by appropriate fish species. Experimental studies have shown that periphyton substrates can increase by 50% the yield of fish in ponds with no supplemental feeding and reach 5 t/ha/year (Van Dam *et al.*, 2002).

Conclusion

The Chinese government and scientists are well aware of the development of intensive monoculture (Li, 2001). However, there are still some prospects for polyculture. The international market for luxury fish is restricted and the volume of exportable Chinese aquatic food products is limited. The selling price of the luxury items will decrease as the supply increases (see the salmon now at $1.5 per kg). A part of the Chinese market for luxury seafood will be covered by imports (Guo, 2000) and will be only partly open to Chinese products. The present traditional practices of polyculture and integrated fish farming which have been established empirically can be improved and research programmes are underway; to obtain better technical and economic efficiencies and better quality and safety of the products and to reduce the production costs. Then optimised polyculture systems may remain economically profitable and attractive in a market economy.

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